Phenomenological mass relation for free massive stable particles and estimations of neutrino and graviton masses

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April 15, 2010

Abstract

The ratio between the proton and electron masses was shown to be close to the ratio between the shortest lifetimes of particles, decaying by the electromagnetic and strong interactions. The inherent property of each fundamental interaction is defined, namely the Minimal lifetime of the interaction (*MLTI*). The rest mass of the Lightest free massive stable particle (*LFMSP*), acted upon by a particular interaction, is shown to be inversely proportional to *MLTI*. The found mass relation unifies the masses of four stable particles of completely different kinds (proton, electron, electron neutrino and graviton) and covers an extremely wide range of values, exceeding 40 orders of magnitude. On the basis of this mass relation, the electron neutrino and graviton masses have been approximately estimated to 6.5×10^{-4} eV and $\hbar H/c^2 \approx 1.5 \times 10^{-33}$ eV, respectively. Besides, the last value has been obtained independently by dimensional analysis by means of three fundamental constants, namely the speed of light in vacuum (c), reduced Planck constant ($\hbar$) and Hubble constant (H). It was shown that the rest energy of *LFMSP*, acted upon by a particular interaction, is close to Breit-Wigner's energy width of the shortest living state, decaying by the respective interaction.

Key words: mass relation; neutrino mass limit; graviton mass; dimensional analysis

1 Introduction

Although the neutrino and the graviton belong to different particle kinds (neutral lepton and quantum of the gravitation, respectively), they have some similar properties. Both particles are not acted upon by the strong and the electromagnetic interactions, which makes their detection and investigation exceptionally difficult. Besides, both have masses that are many orders of magnitude lighter

than the masses of the rest particles and they are generally accepted to be massless.

Decades after the experimental detection of the neutrino [1], it was generally accepted that the neutrino rest mass $m_{0\nu}$ is rigorously zero. The first experiment, hinting that the neutrino probably possesses a mass, is dated back to the 60−ies [2]. The total flux of neutrinos from the Sun is about 3 times lower than the one, predicted by theoretical solar models. This discrepancy can be explained if some of the electron neutrinos transform into another neutrino flavor. Later, the experimental observations showed that the ratio between the atmospheric ν_μ and ν_e fluxes was less than the theoretical predictions [3, 4]. Again the discrepancy could be explained by the neutrino oscillations. The crucial experiments with the 50 Kton neutrino detector Super-Kamiokande found strong evidence for oscillations (and hence - mass) in the atmospheric neutrinos [5].

The direct neutrino measurements allow to limit the neutrino mass. The upper limit for the mass of the lightest neutrino flavor ν_e was obtained from experiments for measurement of the high-energy part of the tritium $\beta-$ spectrum and recent experiments yield 2 eV upper limit [6, 7]. As a result of the recent experiments, the upper mass limits of ν_μ and ν_τ were found to be 170 KeV [8] and 18.2 MeV [9], respectively. The Solar and atmospheric neutrino experiments allow to find the square mass differences $\Delta m_{12}^2 = m_2^2 - m_1^2$ and $\Delta m_{23}^2 = m_3^2 - m_2^2$, but not the absolute values of the neutrino masses. The astrophysical constraint of the neutrino mass is $\sum m_\nu <$ 2.2 eV [10]. The recent extensions of the Standard model lead to non-zero neutrino masses, which are within the large range of 10^{-6} eV $\div 10$ eV.

Similarly to the case with the neutrino before 1998, the prevailing current opinion is that the quantum of the gravitation (graviton) is massless. This opinion is connected with Einstein's theory of General Relativity, where the gravitation is described by a massless field of spin 2 in a generally covariance manner. The nonzero graviton mass leads to a finite gravitation range $r_g \sim \lambda_g/2\pi = \hbar/(m_g c)$, where λ_g is Compton wavelength of the graviton. The lowest astrophysical limit of the graviton mass is obtained by rich galactic clusters $m_g < 2 \times 10^{-29} h^{-1}$ eV [11], where $h \approx 0.70$ is a dimensionless Hubble constant. In this case no difference was observed between Yukawa's potential for the massive graviton and Newton's potential for the massless graviton.

It has been obtained a value of the graviton mass $m_g \sim 4.3 \times 10^{-34}$ eV for an infinite stationary universe [12], although the expansion of the Universe is a fact, long ago established. The mass $m_{i\,\mathrm{min}}$ of the Lightest free massive stable particle (*LFMSP*), acted upon by a particular interaction, is shown to be proportional to the coupling constant of the respective interaction at extremely low energy [13]. The graviton and electron neutrino masses have been estimated by this approach to $m_g \sim 2.3 \times 10^{-34}$ eV and $m_{\nu e} \sim 2.1 \times 10^{-4}$ eV, respectively.

2 Minimal lifetime of a fundamental interaction and a mass relation for free massive stable particles

Among the multitude of particles, several free particles are notable, which are stable or at least their lifetimes are longer than the age of the Universe – the proton (p), electron (e), neutrino (ν) (three flavors), graviton (g) and photon (γ). Only *free massive stable* particles are examined in this paper. Quarks and gluons are bound in hadrons by confinement and they cannot be immediately detected in the experiments, and the photon is massless. Therefore, these particles are not a subject of this paper.

A measure for the interaction strength is a dimensionless quantity - the coupling constant of the interaction (α_i), which is determined from the cross section of the respective processes. Generally, it is known that the bigger the strength (coupling constant) of an interaction, the quicker (with shorter duration τ) are the processes, ruled by this interaction. Actually, the typical lifetime of resonances, decaying by the strong interaction (τ_s) is from 10^{-24} s to 10^{-23} s, the time of the radiative decay (τ_e) of particles and excited stages of nuclei is from 10^{-21} s to 10^{-12} s and, the lifetime (τ_w) of particles decaying by the weak interaction is from 10^{-12} s to 10^{3} s. Since "the age of the Universe" is $H^{-1} \sim 4.3 \times 10^{17}\,\mathrm{s} \approx 1.37 \times 10^{10}$ years, the lifetime of particles decaying by the gravitational interaction is $\tau_g \gtrsim H^{-1}$.

The fastest process by the strong interaction is the $f_0(400-1200)$ resonance decay, having $\tau_{s\,\mathrm{min}} \approx 8 \times 10^{-25}\,\mathrm{s}$ [14]. The fastest process by the electromagnetic interaction is the radiative decay of the super hot nuclei $\tau_{e\,\mathrm{min}} \sim \lambda_e/(2\pi c) \approx 1.3 \times 10^{-21}\,\mathrm{s}$, where λ_e is Compton wavelength of the electron [15]. The fastest decay by the weak interaction is flavor transformation of the bottom and charmed quarks with $\tau_{w\,\mathrm{min}} \sim 10^{-12}\,\mathrm{s}$. The minimal lifetime $\tau_{g\,\mathrm{min}}$ of particles, decaying by the gravitational interaction is unknown, therefore we suggest that $\tau_{g\,\mathrm{min}} \sim H^{-1} \approx 4.3 \times 10^{17}\,\mathrm{s}$. Thus, the cosmological expansion of the Universe is considered a manifestation of the gravitational decay. Therefore, the minimal lifetime ($\tau_{i\,\mathrm{min}}$) of particles, decaying by a particular interaction, appears a *unique inherent property* of each interaction, below named Minimal lifetime of the interaction (*MLTI*).

The ratio between the proton and electron masses is $m_p/m_e \approx 1836$. On the other side, the ratio between the minimal lifetimes of electromagnetic and strong interactions is $\tau_{e\,\mathrm{min}}/\tau_{s\,\mathrm{min}} \sim 1625$. The two ratios differentiate by less than 13 %. Therefore, the ratio between the proton and electron masses is close to the ratio between the minimal lifetimes of the electromagnetic and strong interactions:

$$\frac{m_p}{m_e} \sim \frac{\tau_{e\,\mathrm{min}}}{\tau_{s\,\mathrm{min}}} \tag{1}$$

The proton and electron are the Lightest free massive stable particles (*LFMSP*), acted upon by the strong and electromagnetic interactions, respectively. This

relation is remarkable since it connects the masses of *LFMSP*, acted upon by the strong and electromagnetic interactions and the respective *MLTI*. The relation (1) suggests that the mass of *LFMSP*, acted upon by the strong (or the electromagnetic) interaction is inversely proportional to the respective *MLTI*, i.e. $m_p \approx k/\tau_{s\,\mathrm{min}}$ and $m_e \approx k/\tau_{e\,\mathrm{min}}$, where k is a constant. Therefore, it is interesting to examine whether this rule will be valid both for the weak interaction, whose *MLTI* is several orders of magnitude longer than the minimal lifetime of the electromagnetic interaction and for the gravity, whose minimal lifetime is dozens orders of magnitude longer than minimal lifetime of the weak interaction. *LFMSP* acted upon by the weak interaction is the electron neutrino and *LFMSP* acted upon by the gravity most probably appears the hypothetical graviton. Although the rest masses of the two particles are still unknown, the direct neutrino mass experiments and the theoretical models suggest that the ν_e mass is between 10^{-6} eV and 2 eV, i.e. ν_e is several orders of magnitude lighter than the electron. Again, the astrophysical constraints allow to find the upper limits of the graviton mass and according to these constraints, if the graviton really exists, its mass would be less than 3×10^{-29} eV, i.e. dozens orders of magnitude lighter than ν_e. Table 1 presents *MLTI*, as well as the masses of *LFMSP*, acted upon by the respective interaction. The experimental upper limits of the electron neutrino and graviton masses are also presented. Table 1 shows that the mass of *LFMSP* acted upon by a particular interaction decreases with the increase of *MLTI*.

Table 1: MLTI and the masses of LFMSP acted upon by the respective interaction.

Interaction	*MLTI* (s)	*LFMSP*	Experimental mass or mass limit of *LFMSP* (eV)
Strong	8×10^{-25}	p	9.38×10^{8}
Electromagnetic	1.3×10^{-21}	e	5.11×10^{5}
Weak	10^{-12}	ν_e	$0 < m < 2$
Gravitational	4.3×10^{17}	g	$< 3 \times 10^{-29}$

The data from Table 1 have been presented in a double-logarithmic scale in Fig. 1, which shows that the trend is clearly expressed.

The points in Fig. 1, corresponding to the electron and proton masses and to the upper limit masses of the electron neutrino and graviton, are approximated by the least squares with a power law:

$$\log m_{\mathrm{min}} = -0.90 \log \tau_{\mathrm{min}} - 12.20 \tag{2}$$

Although this approximation is only on four points, the found correlation is close and the correlation coefficient reaches $r = 0.998$, which supports the power law. The modulus of the slope (S) is little smaller than one and that is why it can be said that the regression is close to a linear one. In addition, it should be reminded that instead of the electron neutrino and graviton masses, their upper limit values are used, which produce a certain underestimation of the S value.

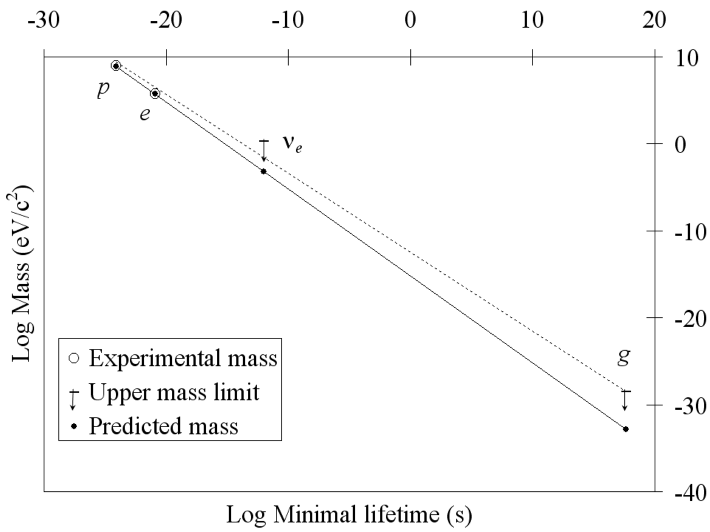

Figure 1: Dependence between the mass of *LFMSP* acted upon by a particular interaction and *MLTI*. The dashed line represents the approximation (2) of e, p and the upper limit masses of g and ν_e. The solid line represents the strict inverse linear approximation ($S = -1$).

This approximation shows that the mass of *LFMSP*, acted upon by a particular interaction, increases with the decrease of the respective *MLTI* by a power law with $S \sim -1$, i.e. close to the inverse linear one. The inverse proportionality of the proton mass to the strong coupling constant and of the electron mass to the fine structure constant also support inverse linear dependence (*without intercept*). Thus, the experimental data suggest inverse linear dependence ($S = -1$) between the mass of *LFMSP* acted upon by a particular interaction and *MLTI*:

$$\log m_{\min} = -\log \tau_{\min} - k_0 \tag{3}$$

where k_0 is a constant.

The expression (3) transforms into:

$$m_{\min}\tau_{\min} = 10^{-k_0} = k \tag{4}$$

In this way the experimental data and constraints suggest that the mass of *LFMSP*, acted upon by a particular interaction, is inversely proportional to the respective *MLTI*:

$$m_{i\,\min} = \frac{k}{\tau_{i\,\min}} \tag{5}$$

where $k = m_e \tau_{e\,\min} = 6.54 \times 10^{-16}\,\mathrm{eV\,s} = 1.16 \times 10^{-51}\,\mathrm{kg\,s}$ is a constant, $i = 1, 2, 3, 4$ – index for each interaction and *LFMSP* acted upon by the respective interaction.

In consideration of $\tau_{e\,\min} \sim \lambda_e/(2\pi c)$ and Compton formula $\lambda_e = h/(m_e c)$, the mass relation (5) would be transformed in the equivalent mass formula:

$$m_{i\,\min} = \frac{m_e \tau_{e\,\min}}{\tau_{i\,\min}} \sim \frac{\hbar}{c^2 \tau_{i\,\min}} \tag{6}$$

3 Neutrino and graviton mass estimations

The found mass relation (5), and equivalent mass formula (6), could be examined by the strong interaction because the proton mass is measured with high precision. The application of the mass relation on the strong interaction predicts the lightest stable hadron mass $m_p \approx 819\,\mathrm{MeV}$. Thus, the proton mass value obtained by the mass relation (5) is only 12.7 % lower than the experimental value of m_p. This result confirms the reliability of the found mass relation and shows that this relation possesses heuristic power. The application of the mass relation (5) on the weak interaction allows to evaluate the mass of the electron neutrino $m_{\nu e} \approx 6.5 \times 10^{-4}\,\mathrm{eV}$. This value is in order of magnitude of the estimation of the electron neutrino mass, found in [13].

The above obtained value $m_{\nu e} \approx 6.5 \times 10^{-4}\,\mathrm{eV}$ and the results from the solar and atmospheric neutrino experiments allow to estimate the masses of the heavier neutrino flavor – ν_μ and ν_τ. The results from the Super Kamiokande experiment lead to square mass difference $\Delta m^2_{23} \sim 2.7 \times 10^{-3}\,\mathrm{eV}^2$ [16]. Recent results on solar neutrinos provide hints that the Large mixing angle (*LMA*) of Mikheyev-Smirnov-Wolfenstein (*MSW*) solution is more probable than the Small mixing angle (*SMA*) [17]. The *LMA* leads to $\Delta m^2_{12} \sim 7 \times 10^{-5}\,\mathrm{eV}^2$ [18] and the *SMA* leads to $\Delta m^2_{12} \sim 6 \times 10^{-6}\,\mathrm{eV}^2$ [19]. In this way both solutions yield $m_{\nu\tau} \sim 0.05\,\mathrm{eV}$. The most appropriate *LMA* yields $m_{\nu\mu} \sim 8.4 \times 10^{-3}\,\mathrm{eV}$ and the *SMA* leads to $m_{\nu\mu} \sim 2.5 \times 10^{-3}\,\mathrm{eV}$. Thus, the obtained values of the neutrino masses support the normal hierarchy case. These values are close to the predictions of the simple $SO(10)$ model for the neutrino masses [20].

In consideration of $\tau_g \sim H^{-1}$, the mass formula (6) allows to estimate the graviton mass:

$$m_g \sim \frac{\hbar}{c^2 \tau_g} \sim \frac{\hbar H}{c^2} \approx 1.5 \times 10^{-33}\,\mathrm{eV} \tag{7}$$

The predicted masses of four *LFMSP* are presented in Table 2, where it can be seen that the fitting of the predicted values and the experimental data is satisfactory.

The exceptionally small graviton rest mass seriously impedes its experimental determination. Yet, it can be expected that appropriate astrophysical or laboratory experiments would be conducted for this aim. Probably, the investigations of the large-scale structure of the universe and the microwave background radiation would contribute to the astrophysical estimation of the graviton mass.

Table 2: Experimental and predicted values of the masses of LFMSP.

Particle	Experimental mass or mass limit (eV)	Predicted mass (eV) [This paper]	Predicted mass (eV) [13]
p	9.38×10^8	8.19×10^8	9.8×10^8
e	5.11×10^5	5.11×10^5	5.11×10^5
ν_e	$0 < m < 2$	6.5×10^{-4}	2.1×10^{-4}
g	$< 3 \times 10^{-29}$	1.5×10^{-33}	2.3×10^{-34}

The massive graviton might turn of considerable importance for the description of the processes in the nuclei of the active galaxies and quasars, the gravitational collapse as well as for the improvement of the cosmological models.

Besides, the formula (7) for graviton mass could be obtained *independently* by dimensional analysis. Actually, by means of three fundamental constants, namely the speed of light in vacuum (c), reduced Planck constant ($\hbar$) and Hubble constant (H), a mass dimension quantity m_x could be constructed:

$$m_x = kc^\alpha \hbar^\beta H^\gamma \tag{8}$$

where k is dimensionless parameter of the order of magnitude of one and α, β and γ are unknown exponents, which will be determined by dimensional analysis below.

Dimensional analysis has been successfully used in [21] for estimation of mass of the observable universe by means of following fundamental constants – the speed of light (c), universal gravitational constant (G) and Hubble constant (H).

The dimensions of the left and right sides of the equation (8) must be equal:

$$[m_x] = [c]^\alpha [\hbar]^\beta [H]^\gamma \tag{9}$$

Taking into account the dimensions of quantities in formula (9) we obtain:

$$L^0 T^0 M^1 = (LT^{-1})^\alpha (ML^2T^{-1})^\beta (T^{-1})^\gamma = L^{\alpha+2\beta} T^{-\alpha-\beta-\gamma} M^\beta \tag{10}$$

where L, T and M are dimensions of length, distance and mass, respectively. From (10) we obtain the system of linear equation:

$$\begin{aligned} \alpha + 2\beta &= 0 \\ -\alpha - \beta - \gamma &= 0 \\ \beta &= 1 \end{aligned} \tag{11}$$

Solving the system we find the exponents $\alpha = -2, \beta = 1, \gamma = 1$. Replacing the obtained values of the exponents in equation (8) we find the formula (12) for the graviton mass:

$$m_x \sim \frac{\hbar H}{c^2} \tag{12}$$

Although this formula has been found by totally different approach, it coincides with formula (7), which reinforces the found phenomenological mass relation (6).

According Big Bang cosmology [22], Hubble constant decrease with age of the universe, therefore the found graviton mass (7) slowly decrease with time. On the other hand, according Tired Light model [23] and Steady State theory [24], the Hubble constant H is truly a constant not only in all directions, but at all time. Therefore, the graviton mass is truly constant in the framework of Tired Light model and Steady State theory.

4 Discussions.

From mass formula (6) we obtain:

$$m_{i\,\min}c^2 \sim \frac{\hbar}{\tau_{i\,\min}} \approx \Gamma_{i\,\min} \tag{13}$$

where $\Gamma_{i\,\min}$ is Breit-Wigner's energy width of the shortest living state, decaying by the respective interaction.

Therefore, the rest energy of *LFMSP* acted upon by a particular interaction is close to Breit-Wigner's energy width of the shortest living state, decaying by the respective interaction. It should be reminded that here $\tau_{i\,\min}$ isn't the lifetime of the particle (it is stable) but $\tau_{i\,\min}$ is the respective *MLTI*.

The mass formula (6) would be written in the form:

$$m_{i\,\min}c^2\tau_{i\,\min} \sim \hbar \tag{14}$$

The mass (m_i) of each free massive stable particle, acted upon by a particular interaction $m_i \geq m_{i\,\min}$ and the lifetime (τ_i) of particles decaying by the respective interaction $\tau_i \geq \tau_{i\,\min}$. As a result, the inequality (15) is obtained:

$$m_i c^2 \tau_i \geq \hbar \tag{15}$$

The comparison of (15) and the Uncertainty Principle $\Delta E \Delta t = \Delta(mc^2)\Delta t \geq \hbar$ shows that the inequality (15), which results from the mass formula (6), is related to the Uncertainty Principle. Thus, equation (14) appears a boundary case of the Uncertainty Principle at minimal allowed values of the rest energy and lifetime of the real particles. In this case, however, a more general interpretation of the Uncertainty Principle will be necessary since equation (14) relates the mass ($m_{i\,\min}$) of *LFMSP* acted upon by a particular interaction with minimal lifetime ($\tau_{i\,\min}$) of particles (states), decaying by the respective interaction. The future complete Unified theory of the four interactions would give theoretical explanation of this dependence. Most probably $\tau_{i\,\min}$ determines inability of the respective interaction to create free massive stable particles, possessing rest mass $m_i \leq m_{i\,\min} = \hbar/(c^2\tau_{i\,\min})$. In other words, the stronger an interaction the smaller is *MLTI* and the heavier is *LFMSP*, which it is capable to create.

The mass relation (16) has been obtained in [13] by a similar phenomenological approach:

$$m_{i\,\min} = \frac{m_e}{\alpha}\alpha_i(0) \tag{16}$$

where $m_{i\,\min}$ is the mass of *LFMSP*, acted upon by a particular interaction, $\alpha_i(0)$ is the coupling constant of a particular interaction at extremely low energy $E \sim m_e c^2$ and α is the fine structure constant.

From (16) and (6) we obtain:

$$\alpha_i(0) = \frac{\alpha m_{i\,\min}}{m_e} = \frac{\hbar\alpha}{m_e c^2 \tau_{i\,\min}} = \frac{\alpha\lambda_e/2\pi}{c\tau_{i\,\min}} \sim \alpha\frac{\tau_{e\,\min}}{\tau_{i\,\min}} \approx \frac{\tau_n}{\tau_{i\,\min}} \tag{17}$$

where τ_n is the nuclear time.

Equation (17) supports the natural suggestion that the coupling constant of a particular interaction at extremely low energy $\alpha_i(0)$ is inversely proportional to *MLTI* and it determines from the ratio $\tau_n/\tau_{i\,\min}$.

It is worth noting that each *LFMSP*, acted upon by a particular interaction also appears the lightest free massive particle, possessing the respective *universal conserving quantity* - baryon number, electric charge, lepton number and mass. Actually, p, e, ν_e, and g are *LFMSP*, acted upon by the strong, electromagnetic, weak and gravitational interaction, respectively, and they also appear lightest free massive particles, possessing baryon number, electric charge, lepton number and mass. It should also be mentioned that all four lightest free massive particles, possessing universal conserving quantity are stable or, at least their lifetimes are longer than the age of the Universe.

The massive graviton rises severe challenges before the modern unified theories. Among them are van Dam-Veltman-Zakharov ($vDVZ$) discontinuity [25, 26] and the violation of the gauge invariance and the general covariance. There are, however, already encouraging attempts to solve $vDVZ$ discontinuity in anti de Sitter (AdS) background [27, 28].

5 Conclusions

It was found that the ratio between the proton and electron masses is close to the ratio between the shortest lifetime of particles, decaying by the electromagnetic and strong interaction $m_p/m_e \sim \tau_{e\,\min}/\tau_{s\,\min}$. The inherent property of each fundamental interaction is defined, namely the Minimal lifetime of the interaction ($MLTI$). Inverse proportionality has been found between *MLTI* as well as the rest mass of the *LFMSP* acted upon by the respective interaction $m_{i\,\min} = k/\tau_{i\,\min} \sim \hbar/(c^2\tau_{i\,\min})$.

The rest mass of the electron neutrino has been obtained by this approach to $m_{\nu e} \approx 6.5 \times 10^{-4}\,\text{eV}$. The masses of the heavier neutrino flavors have been estimated by the results of the solar and atmospheric neutrino experiments. The mass of ν_τ is estimated to $0.05\,\text{eV}$ and the mass of ν_μ is estimated to $8.4 \times 10^{-3}\,\text{eV}$ for *LMA* and $2.5 \times 10^{-3}\,\text{eV}$ for *SMA*. The graviton rest mass has

been estimated by this approach $m_g \sim \hbar H/c^2 \approx 1.5 \times 10^{-33}$ eV. Besides, the last value has been obtained independently by dimensional analysis by means of the fundamental constants c, $\hbar$ and H.

It has been found that the rest energy of *LFMSP*, acted upon by a particular interaction, is close to Breit-Wigner's energy width of the shortest living state, decaying by the respective interaction. It has been shown that the mass formula for free massive stable particles $m_{i\,\min} = \hbar/(c^2 \tau_{i\,\min})$ probably involves the Uncertainty Principle.

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